

ECE214: Electrical Circuits Laboratory
Lab #8 — Boost Converters
Week of 31 March 2015

1 Introduction

This is the first in a series of three labs that will culminate in a circuit that will convert a 9 Volt DC source into a 45 Volt DC source. A block diagram of the system you will design is shown in Figure 1 below.

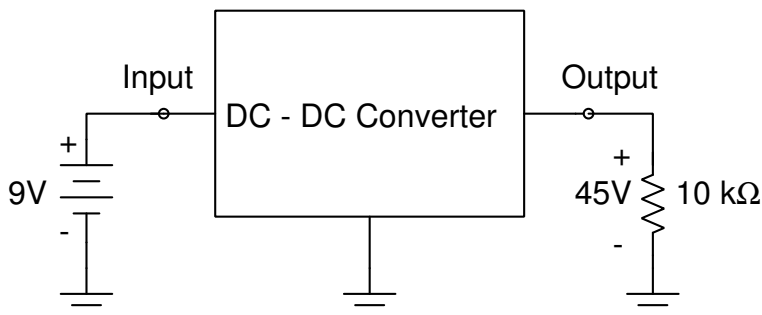


Figure 1: Block diagram of the DC–DC converter.

It is important that you understand how this DC–DC converter works, and are able to explain and describe how the various sub-circuits function. You will write a detailed lab report describing: how the circuits function, the theory of operation, the design of the DC–DC converter, the simulation results and the experimental results. You will get details on the format and content of the final report in both the ECE214 and ECP214 lectures. Once all three labs in this series are completed, the final writeup will be due on 1 May 2015.

1.1 Switch Boost Circuit

In this lab, you will design, build and test a boost-circuit, which is one sub-circuit of the DC–DC converter. Boost circuits are used in many applications to produce a higher DC voltage from a low voltage source such as a battery. One basic type of boost circuit is shown in Figure 2.

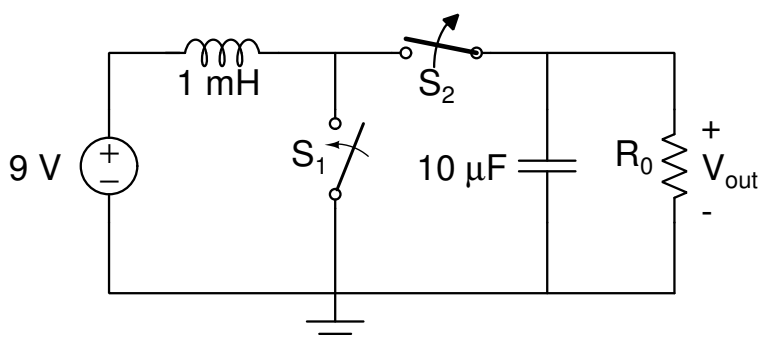


Figure 2: A basic boost circuit implemented with two synchronized switches.

In this circuit, the two switches operate simultaneously and in opposite directions:

- When switch S_1 closes, switch S_2 opens; when switch S_1 opens, switch S_2 closes. Switches S_1 and S_2 are never both open or both closed at the same time.
- Switches S_1 and S_2 are continuously opened and closed by an oscillator circuit that is not shown. (The oscillator circuit is the subject of Lab 9.)
- When switch S_1 is closed and S_2 is open, the 9 V supply voltage and the inductor form one circuit, and the capacitor and the resistor form a second circuit. These circuits are isolated and not connected to each other. The voltage across the capacitor will decrease as the capacitor is discharged through resistor R_0 . This decrease in voltage will depend on how long the switch is open and the value of the resistor R_0 . At the same time, current through the inductor increases. The maximum current flow will depend on how long switch S_1 is closed and on the series resistance of the inductor and the switch S_1 . The maximum current through the inductor should never be more than 0.5 A (if the current gets too high the core will saturate and the inductor will turn to a short circuit).
- When switch S_1 is opened and S_2 is closed, the two circuits are connected and the energy in the inductor will pass through switch S_2 and be supplied to the $10\mu F$ capacitor. The voltage on the capacitor will increase and drive current through the resistor R_0 . A steady-state output voltage is reached when the energy transferred from the inductor to the capacitor when switch S_1 is open and switch S_2 is closed equals the energy lost from the capacitor when switch S_1 is closed and switch S_2 is open.

1.2 Diode Boost Circuit

Rather than implement this circuit with two switches, you will design the boost circuit using a diode in place of switch S_2 as shown in Figure 3. When switch S_1 is opened, the energy in the inductor is released and charge passes through diode D_1 and into the capacitor. The diode allows current to pass in only one direction. Once charge has passed through the diode onto the capacitor it can not return to the inductor side of the circuit. It only allows current to pass when switch S_1 is open and functions as an open circuit when switch S_1 closes.

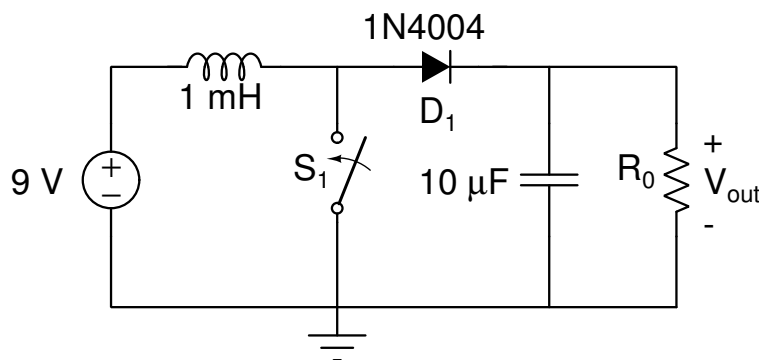


Figure 3: A basic boost circuit using a diode to replace switch S_2 .

2 Pre-Lab

Design a boost-circuit which takes an input voltage of 9 VDC and produces an output voltage of 20 VDC with a peak-to-peak ripple of less than 0.1 V. Record all hand-calculations and answers to the following questions in your notebook.

1. If V_{out} decreases from 20 V to 19.9 V when switch S_1 is closed, how much energy must be supplied to the capacitor when switch S_1 is open to bring the voltage back to 20 V?
2. Let t_1 be the duration that switch S_1 is closed. What is the value of t_1 to allow the inductor to absorb this much energy? Assume the inductor has a series resistance of 0.5Ω and the switch has a resistance when closed of 1Ω .
3. What is the maximum current through the inductor just before switch S_1 opens?
4. What value of R_0 is required such that the capacitor voltage drops from 20 V to 19.9 V during time t_1 ?
5. How much energy is lost in the resistor R_0 when switch S_1 is closed?
6. Let t_2 be the amount of time it will take for the current to stop flowing from the inductor to the capacitor after switch S_1 is open. Approximate the value of t_2 .
7. The period of the square wave used to drive switch S_1 is $T = t_1 + t_2$. What is T ?
8. Using the above values for T , C , and R_0 , how much current can the boost-circuit deliver?
9. How much power must R_0 absorb?
10. Use Micro-Cap to simulate the boost-circuit shown in Figure 4.

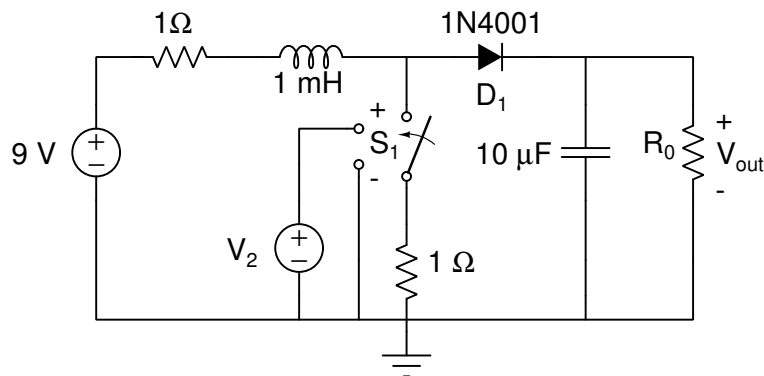


Figure 4: Test circuit representation of the boost circuit for Micro-Cap simulation.

This circuit represents an approximation of what you will build in the lab. The switch is modeled in Micro-Cap as a voltage controlled switch $S(V\text{-Switch})$. This switch is available in Micro-Cap under *menus* → *Components* → *AnalogPrimitive* → *SpecialPurpose*. Choose the SBREAK2 model for this circuit. Set the “on resistance” of the switch to 1Ω and the “off resistance” to $10^6\Omega$. The switch is closed when the control voltage is 5 V and open when the control voltage is 0 V.

- Set the value of R_0 to what you calculated above.
- Set V_2 to a square wave from 0 to 5 V with a period of T and the pulse width of t_1 calculated above.
- Plot the voltage across the capacitor and the current through the inductor for a time duration of 5 ms. This will show the continuous running state of the circuit.
- What is the output voltage V_{out} ?
- How much ripple do you observe?
- If the values of t_1 , t_2 , and R_0 are correct, you should see an output voltage of 20 V with a ripple of 0.1 V.
- Redesign the circuit if necessary to meet the specification. If the output voltage and ripple are close to the specification, you can adjust the output voltage by making small changes to the values of t_1 , t_2 , and R_0 . Make sure the plot of your output voltage shows that your design meets the specification .
- Have a table listing the final values of t_1 , t_2 and R_0 and a plot of the output voltage in your notebook and reference the table and plot in the table of contents.

3 Lab Procedure

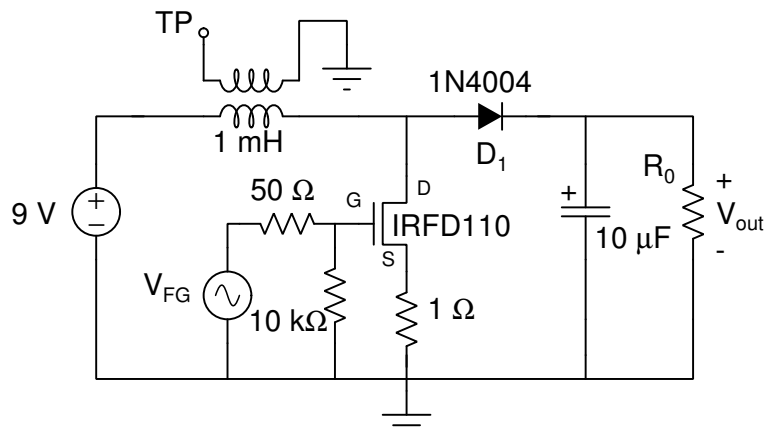


Figure 5: Boost circuit.

Build and test the boost-circuit. The schematic is shown in Figure 5. A MOSFET transistor (IRFD110) is used as a solid-state voltage-controlled switch. Try to place the circuit near the end of your breadboard (and don't disassemble the circuit at the end of the lab), as you will eventually need two boost-circuits on the breadboard to meet the specifications in Lab 10. Record all results in your laboratory notebook.

- Build the boost-circuit shown in Figure 5 but do **not** apply the 9 volt power supply.
- Make sure you have a resistor bank for the load resistor R_0 with the resistance value calculated in the pre-lab. Make sure your resistor bank can handle the power you will be supplying to these resistors.
- Set the Function Generator to produce a square wave signal from 0 volts to 5 volts with a period of T_s and duty cycle of $\frac{t_1}{T}$. Check the signal on the scope to make sure it is correct before applying it to the circuit.

4. Apply the signal to the circuit.
5. Attach one channel of the the scope across the capacitor and the second channel across the 1Ω resistor in series with the transistor. Monitor these voltages carefully when powering up the circuit. Make sure the maximum current through the transistor never exceeds 0.5A and the voltage across the capacitor does not exceed 25 V.
6. Turn the 20 V DC supply voltage down to zero and then connect it to the inductor where the +9 volts is indicated.
7. Slowly turn up the DC supply voltage until it reaches 9 V. If the voltage across the capacitor goes above 25 V, or the current through the transistor exceeds 0.5 A, immediately reduce the supply voltage. Adjust the magnitude of the load resistor or change the period and/or pulse width of the function generator to correct the problem. If either signal can't be kept within limits check your circuit.
8. Record the voltage across the capacitor in your notebook. Measure the average DC value using your DVM and the ripple using the scope. Ripple is the AC signal riding on the DC part. Does it meet the 0.1 Vp ripple limit?
9. Record the current in the transistor. Does it ever exceed 0.5 amps? Record all results in your notebook.
10. If the circuit does not meet the specification, redesign and retest the circuit. If you can not meet the specification, state the best results you were able to obtain. Take a photograph showing your final circuit with the output displayed on a DVM. Also include a photograph showing the AC ripple on an oscilloscope. Include these photos in your notebook and reference them in the table of contents.
11. Wind an additional coil of about 10 turns on the toroidal inductor used in this lab (you will have to peel off the black protective layer from the inductor). This turns the inductor into a transformer and will allow you to look at the voltage across the inductor without connecting to the inductor windings. Connect one end of your coil to ground in the circuit and leave the other end TP (Test Point) free. Use the TP winding on the coil to look at the voltage that appears across the transformer. This is a transformer in action. Record in your notebook the signal at TP.

If you have time, you may want to start the design a 2nd boost-circuit. This circuit will use the output of the first boost-circuit as an input voltage and produce an output voltage of 45 V. These two circuits will be needed in Lab 10.

4 Post-Lab

None, but your final results will be looked at as part of the post-lab grading.